REMARKS

Claims 11, 12, 34, and 35 are canceled. New claims 93-98 are added. After amendment, claims 1-10, 13-33, 36-46, and 93-98 are pending. New claims 93-98 are supported by, for example, paragraphs [0013] and [0036].

Applicants affirm the election of claims 1-46.

Claims 29-31 are rejected under 35 U.S.C. 112 as lacking antecedent basis. Applicants respectfully submit that claims 29-31, as amended, meet the requirements of 35 U.S.C. 112.

Claims 1-3, 6, 7, 9-21, 25, 27, 28, and 31-44 are rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos et al., U.S. Patent No. 5,955,749 (hereinafter "Joannopoulos") in view of Imada et al, *Coherent two-dimensional lasing action in surface-emitting laser with triangular-lattice photonic crystal structure*, 75 Applied Physics Letter 316 (1999) (hereinafter "Imada"). Applicants respectfully traverse the rejection.

Claims 1 is amended to recite "a second semiconductor layer doped with a second dopant, . . . <u>a second electrode layer</u> <u>on said second semiconductor layer</u>; and a periodically-arranged <u>plurality of holes formed in the second semiconductor layer</u> and extending towards the first semiconductor layer." Claim 1 therefore teaches a device with an electrode on a layer with a plurality of holes.

In contrast, in Imada's device, the n-InP clad layer with a triangular lattice structure is sandwiched between planar semiconductor layers. The electrodes are formed on <u>planar semiconductor layers, not on layers with a plurality of holes</u>. See Imada's FIG. 1(a). As noted by the Examiner in paragraph 10 of the office action, Joannopoulos does not teach any electrode structure. Thus, even in combination, Joannopoulos and Imada do not teach all the elements of claim 1. In addition, neither reference teaches or suggests modifying Imada's electrodes for use on a layer with a plurality of holes, and neither reference teaches or

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suggests how Imada's electrodes could be modified for use on a layer with a plurality of holes. Accordingly, claim 1 is patentable over the combination of Joannopoulos and Imada.

Claims 2, 3, 6, 7, 9, 10, and 13-21 depend from claim 1 and are therefore allowable for at least the reasons stated above for claim 1. In addition, regarding claim 6, the Examiner states in paragraph 13 of the office action that "the surface recombination velocity is inherent in the structure." Applicants respectfully submit that the surface recombination velocity is not inherent in the structure, and can be influenced by the manner in which the holes are formed. For example, some fabrication techniques can damage the crystal layer or layers in which the holes are formed, which may increase the surface recombination velocity in a device. Since a surface recombination velocity less than 10^5 cm/sec is not inherent in the structures taught by Joannopoulos and Imada, claim 6 is allowable for this additional reason.

Regarding claims 18 and 19, the Examiner states in paragraph 21 that "emission at or near the band edge is inherent in the function of the device." Applicants respectfully submit that the photonic crystal band structure, including the density of states at the band edges, can change depending on the lattice parameter, the depth of the holes, and the dielectric constant of the material in the holes, as taught in paragraph [0039] of the application. Accordingly, whether the "energy of said emitted light lies close to an edge of a band of the photonic crystal band structure" as recited in claim 18 depends on the particular photonic band structure in a device, and is therefore not inherent in the function of Joannopoulos' or Imada's devices. Claims 18 and 19 are allowable for this additional reason.

Claim 25 is amended to recite "a periodically arranged plurality of holes formed in the second semiconductor layer and extending towards the first semiconductor layer, wherein . . . at least one of said first semiconductor layer, said active layer, and said second semiconductor layer comprises <u>a group III element and nitrogen</u>." Neither Joannopoulos nor Imada teach

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forming a plurality of holes in a layer of a III-nitride device, thus claim 25 is patentable over the combination of Joannopoulos and Imada.

In rejecting claim 26, the Examiner adds Vaudo et al., U.S. Patent No. 6,156,581 (hereinafter "Vaudo") to the combination of Joannopoulos and Imada. Vaudo is cited as teaching a GaN based light emitting diode. The Examiner states "[i]t would have been obvious to use the GaN material system instead of the GaAs shown by Joannopoulos et al. to provide a wider range of available wavelengths." See paragraph 27 of the office action. Applicants respectfully traverse the rejection. A person of skill in the art would have no expectation that implementing Joannopoulos' device in the III-nitride system would result in a functioning device. Joannopoulos teaches "a light emitting device comprising a substrate and a dielectric structure having at least a two-dimensionally periodic variation of dielectric constant which exhibits a spectrum of electromagnetic modes including guided modes of frequencies below a predetermined frequency cutoff and radiation modes of frequencies above and below said predetermined frequency cutoff, <u>the two-dimensionally periodic variation of dielectric constant of the dielectric structure introducing a band gap between the guided modes</u>." Thus, a contrast between the dielectric constant of the material in which the holes are formed and the material filling the holes is necessary to create a photonic structure. It is well known in the art that III-arsenide layers and III-phosphide materials such as the layers that form Joannopoulos' and Imada's devices have much high indices of refraction, and therefore dielectric constants, than III-nitride layers. A person of skill in the art would not expect that the difference between the dielectric constant of a III-nitride layer with holes and the dielectric constant of a material filling the holes (air, for example) would be large enough to create a photonic structure. Accordingly, it would not have been obvious to implement the structures taught by Joannopoulos or Imada in the Vaudo's III-nitride system, because such a combination would give no expectation of success. Thus, claim 25 is allowable over the

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combination of Joannopoulos, Imada and Vaudo. Claims 27, 28, and 31-44 depend from claim 25 and are therefore allowable for at least the same reasons. Claims 27, 41, and 42 are also allowable for the additional reasons described above in the discussion of claims 6, 18, and 19.

Claims 4, 5, and 29-31 are rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos in view of Imada and Kurahashi. Claims 4 and 5 depend from claim 1. Claims 29-31 depend from claim 25. Kurahashi adds nothing to the deficiencies of Joannopoulos, Imada, and Vaudo with respect to claims 1 and 25, accordingly claims 4, 5, and 29-31 are allowable for at least the same reasons as claims 1 and 25.

Claims 8, 22, 23, 26, 45 and 46 are rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos in view of Imada and Vaudo. Claims 8, 22, and 23 depend from claim 1. Claims 26, 45, and 46 depend from claim 25. As described above, claim 25 is allowable over the combination of Joannopoulos, Imada and Vaudo. Vaudo adds nothing to the deficiencies of Joannopoulos and Imada with respect to claim 1. Accordingly, claims 8, 22, 23, 26, 45 and 46 are allowable for at least the same reasons as claims 1 and 25.

Claim 24 is rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos in view of Imada and further in view of Roberts et al., U.S. Patent No. 6,335,548 (hereinafter "Roberts"). Claim 24 depends from claim 1. Roberts adds nothing to the deficiencies of Joannopoulos and Imada with respect to claim 1. Accordingly, claim 24 is allowable for at least the same reason as claim 1.

In view of the above arguments, Applicants respectfully request allowance of all

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pending claims. Should the Examiner have any questions, the Examiner is invited to call the undersigned at (408) 382-0480.

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ATTACHMENT A

IN THE CLAIMS

Claims are amended as follows:

1. (Amended) A light emitting diode comprising:

a first semiconductor layer doped with a first dopant, coupled to a first electrode layer;

an active layer overlying said first semiconductor layer, capable of emitting light;

a second semiconductor layer doped with a second dopant, overlying said active layer, said first dopant and said second dopant being of opposite type; [and]

a second electrode layer [overlying] on said second semiconductor layer[, wherein

at least one of said active layer and said second semiconductor layer has a periodically varying thickness with alternating maxima and minima,]; and

a periodically-arranged plurality of holes formed in the second semiconductor layer and extending towards the first semiconductor layer, wherein

the ratio of the period of said periodic [variation] arrangement and the wavelength of said emitted light in air is greater than about 0.1 and less than about 5; and

at a minimum depth, the depth of at least one of the plurality of holes is such that a thickness of said second semiconductor layer at a bottom of said [minima] at least one of the plurality of the holes is less than about one wavelength of said emitted light in said second semiconductor layer.

9. (Amended) The light emitting diode of claim 1, wherein

said periodically [varying thickness]-arranged plurality of holes is periodic in at least one direction parallel to [the] a plane of said second semiconductor layer[, wherein

said second semiconductor layer has a plane, and said plane has one or more directions].

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10. (Amended) The light emitting diode of claim 1, wherein

said [second semiconductor layer has] periodic arrangement comprises a planar lattice of [through] holes [aligned with said minima].

15. (Amended) The light emitting diode of claim 14, wherein

said emitted light has an intensity and a polarization and the intensity of said emitted light is substantially independent of the polarization[, wherein said emitted light has an intensity and a polarization].

16. (Amended) The light emitting diode of claim 1[0], wherein

said holes are filled with a dielectric.

18. (Amended) The light emitting diode of claim 1, wherein

the periodically-arranged plurality of holes form a photonic crystal having a photonic crystal band structure comprising one or more bands with edges; and

[the] an energy of said emitted light lies close to an edge of a band of the photonic crystal band structure[of said at least one of said active layer and said second semiconductor layer with periodically varying thickness, wherein

said at least one of said active layer and said second semiconductor layer has a photonic band structure, comprising one or more bands, having edges].

19. (Amended) The light emitting diode of claim 18, wherein

the product of a rate of spontaneous emission of the light emitting diode and an efficiency of light extraction of the light emitting diode is greater at an energy close to said band edge than at a plurality of energies away from said band edge[, wherein said light emitting diode has a rate of spontaneous emission and an efficiency of light extraction].

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21. (Amended) The light emitting diode of claim 1, wherein

[the] an intensity of light[,] emitted in [the] a direction substantially normal to [the] a plane of said second semiconductor layer[,] is greater[,] than [the] an intensity of light[,]

emitted in a direction substantially different from the normal of the plane of said second semiconductor layer[, wherein said second semiconductor layer has a plane and a normal].

22. (Amended) The light emitting diode of claim 1, wherein

said first semiconductor layer and said second semiconductor layer each comprise [AlInGaN] at least one layer of a III-nitride material;

said active layer comprises InGaN;

said first and second electrode layers comprise at least one of Ag, Al, and Au;

said periodically-arranged plurality of holes [variation of thickness] is a triangular lattice of holes, wherein

[the] a diameter of said holes is between about 0.3a and about 0.72a, wherein

a is the period of the periodic[ally varying thickness] arrangement[, and said holes have a diameter];

[the] a depth of said holes is between about 0.375a and about 2a[, wherein said holes have a depth];

said first and second semiconductor layers together form an epi-layer, having a thickness between about 0.375a and about 2a; and

said light, emitted by said active layer, has a frequency between about 0.66(c/a) and about 0.75(c/a), wherein c is the speed of light in air.

23. (Amended) The light emitting diode of claim 1, wherein

said first semiconductor layer and said second semiconductor layer each comprise [AlInGaN] at least one layer of a III-nitride material;

said active layer comprises InGaN;

said first and second electrode layers comprise at least one of Ag, Al, and Au;

said periodically-arranged plurality of holes [variation of thickness] is a triangular lattice of holes, wherein

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[the] a diameter of said holes is between about 0.3a and about 0.72a, wherein

a is the period of the periodic[ally varying thickness] arrangement[, and said holes have a diameter];

[the] a depth of said holes is greater than about 2a[, wherein said holes have a depth];

said first and second semiconductor layers together have a thickness greater than about 4a; and

said light, emitted by said active layer has a frequency in one of the ranges of about 0.275(c/a) to about 0.375(c/a) and about 0.58(c/a) to about 0.68(c/a), wherein c is the speed of light in air.

24. (Amended) The light emitting diode of claim 1, wherein

said light emitting diode is disposed in a package, the package comprising:

a support frame;

a heat sink disposed within said support frame for extracting heat from said light emitting diode, wherein

said light emitting diode is disposed over said heat sink;

a plurality of leads, electrically coupled to said light emitting diode; and

a transparent housing overlying the light emitting diode.

25. (Amended) A light emitting diode comprising:

a first semiconductor layer doped with a first dopant;

an active layer overlying said first semiconductor layer, capable of emitting light; [and]

a second semiconductor layer doped with a second dopant overlying said active layer, said first and second dopants being of opposite type[, wherein

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at least one of said active layer and said second semiconductor layer has a periodically varying thickness with alternating maxima and minima,] ; and

a periodically-arranged plurality of holes formed in the second semiconductor layer and extending towards the first semiconductor layer, wherein:

the ratio of the period of said periodic [variation] arrangement and the wavelength of said emitted light in air is greater than about 0.1 and less than about 5; [and]

at a minimum depth, the depth of at least one of the plurality of holes is such that the thickness of said second semiconductor layer at [said minima] a bottom of said at least one of the plurality of holes is less than about one wavelength of said emitted light in said second semiconductor layer; and

at least one of said first semiconductor layer, said active layer, and said second semiconductor layer comprises a group III element and [a group V element] nitrogen.

26. (Amended) The light emitting diode of claim 25, wherein said group III element is Gallium[, and the group V element is Nitrogen].

29. (Amended) The light emitting diode of claim 25, further comprising a first electrode layer, wherein said first semiconductor layer overlies said first electrode layer.

30. (Amended) The light emitting diode of claim 25, further comprising a first electrode layer, wherein

said first electrode layer partially overlies said first semiconductor layer; and

said first semiconductor layer overlies a substrate with a substantially reflective surface.

31. (Amended) The light emitting diode of claim 25, further comprising a first electrode layer and a second electrode layer, wherein

said first electrode layer partially overlies said first semiconductor layer;

said second electrode layer is substantially reflective; and

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said first semiconductor layer overlies a substantially transparent substrate.

32. (Amended) The light emitting diode of claim 25, wherein

said periodically-arranged plurality of holes [varying thickness] is periodic in at least one direction parallel to [the] a plane of said second semiconductor layer[, wherein

said second semiconductor layer has a plane, and said plane has one or more directions].

33. (Amended) The light emitting diode of claim 25, wherein

said [second semiconductor layer has] periodic arrangement comprises a planar lattice of [through] holes [aligned with said minima].

38. (Amended) The light emitting diode of claim 37, wherein

said emitted light has an intensity and a polarization and the intensity of said emitted light is substantially independent of the polarization[, wherein said emitted light has an intensity and a polarization].

39. (Amended) The light emitting diode of claim [33] 25, wherein

said holes are filled with a dielectric.

41. (Amended) The light emitting diode of claim 25, wherein

the periodically-arranged plurality of holes form a photonic crystal having a photonic band structure comprising one or more band with edges; and

[the] an energy of said emitted light lies close to an edge of a band of the photonic crystal band structure [of said at least one of said active layer and said second semiconductor layer with periodically varying thickness, wherein

said at least one of said active layer and said second semiconductor layer with periodically varying thickness has a photonic band structure, comprising one or more bands, having edges].

42. (Amended) The light emitting diode of claim 41, wherein

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the product of a rate of spontaneous emission of the light emitting diode and an efficiency of light extraction of the light emitting diode is greater at an energy close to said band edge than at a plurality of energies away from said band edge[, wherein said light emitting diode has a rate of spontaneous emission and an efficiency of light extraction].

43. (Amended) The light emitting diode of claim 39, wherein

[the] dielectric constants of said dielectric, said first semiconductor layer, and said second semiconductor layer assume values between about 1 and about 16; and

said holes occupy between about 10% and about 50% of the area of said second semiconductor layer.

44. (Amended) The light emitting diode claim of 25, wherein

[the] an intensity of light[,] emitted in [the] a direction substantially normal to [the] a plane of said second semiconductor layer[,] is greater[,] than an [the] intensity of light[,] emitted in a direction substantially different from [the] a normal of the plane of said second semiconductor layer[, wherein said second semiconductor layer has a plane and a normal].

45. (Amended) The light emitting diode of claim 25, wherein

said first semiconductor layer and said second semiconductor layer each comprise [AlInGaN] at least one layer of a III-nitride material;

said active layer comprises InGaN;

said periodically [varying thickness] -arranged plurality of holes is a triangular lattice of holes, wherein

[the] a diameter of said holes is between about 0.3a and about 0.72a, wherein

a is the period of the periodically [varying thickness] -arranged plurality of holes[, and said holes have a diameter];

[the] a depth of said holes is between about 0.375a and about 2a[, wherein said holes have a depth];

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said first and second semiconductor layers together form an epi-layer, having a thickness between about 0.375a and about 2a; and

said light, emitted by said active layer, has a frequency between about 0.66(c/a) and about 0.75(c/a), wherein c is the speed of light in air.

46. (Amended) The light emitting diode of claim 25, wherein

said first semiconductor layer and said second semiconductor layer each comprise [AlInGaN] at least one layer of a III-nitride material;

said active layer comprises InGaN;

said periodically [varying thickness] -arranged plurality of holes is a triangular lattice of holes, wherein

[the] a diameter of said holes is between about 0.3a and about 0.72a, wherein

a is the period of the periodically [varying thickness] -arranged plurality of holes[, and said holes have a diameter];

[the] a depth of said holes is greater than about 2a[, wherein said holes have a depth];

said first and second semiconductor layers together have a thickness greater than about 4a; and

said light, emitted by said active layer has a frequency in one of the ranges of about 0.275(c/a) to about 0.375(c/a) and about 0.58(c/a) to about 0.68(c/a), wherein c is the speed of light in air.

Please add the following new claims:

93. (New) The light emitting diode of claim 1, wherein at least one of the holes extends through the second semiconductor layer and into the active region.

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94. (New) The light emitting diode of claim 1, wherein at least one of the holes extends through the second semiconductor layer, through the active region, and into the first semiconductor layer.

95. (New) The light emitting diode of claim 1, wherein the periodically arranged plurality of holes comprises parallel grooves.

96. (New) The light emitting diode of claim 25, wherein at least one of the holes extends through the second semiconductor layer and into the active region.

97. (New) The light emitting diode of claim 25, wherein at least one of the holes extends through the second semiconductor layer, through the active region, and into the first semiconductor layer.

98. (New) The light emitting diode of claim 25, wherein the periodically arranged plurality of holes comprises parallel grooves.

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